IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	:	
HANNS J. BUESCHELBERGER et al.	:	Examiner:
Serial No.	:	
Filed:	:	
For: OPTICAL FIBER COIL FOR A FIBER-OPTIC MEASURING DEVICE AND A METHOD OF PRODUCING IT	:	Art Unit

FIRST PRELIMINARY AMENDMENT (SUBSTITUTE SPECIFICATION)

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Please amend the patent application transmitted herewith by entry of the attached patent application as a substitute specification in place of the English language translation of International patent application Serial No. PCT/EP 00/05186 and enter the following changes to the claims as they appear in the substitute specification as filed.

IN THE CLAIMS

Cancel Claims 1 through 6 without prejudice.

Add new Claims 7 through 12 as follow:

7. In a method for producing an optical fiber coil for a fiber optic measuring device of the type in which the fiber coil is formed by winding an optical fiber, the improvement comprising the step of applying said optical fiber to a winding body in a quadrupole winding pattern in successive winding layers so that the turns of individual winding layers have, at irregular spacings, as large a number of crossover points as possible whereby nonreciprocal variation is reduced in the light path formed by said fiber.

8. A method as defined in Claim 7, wherein said optical fiber is wound in each winding layer such that said irregular spacings between the individual turns correspond, on average, to approximately half the diameter of said optical fiber.

9. An optical fiber coil for a fiber optic Sagnac interferometer, comprising, in combination:

a) a winding body; and

b) an optical fiber being applied to said winding body in directly successive winding layers in a quadrupole winding pattern with a plurality of irregularly-spaced crossover points in individual winding layers.

10. An optical fiber coil as defined in Claim 9 further including:

a) variable spacings being between turns of each winding layer; and

b) said spacings corresponding, on average, to half the diameter of said optical fiber.

11. An optical fiber coil as defined in Claim 9 wherein a first layer of turns of said optical fiber is applied directly to said winding body.

12. An optical fiber coil as defined in Claim 9 further including a fixing or buffer means between said winding layers.

REMARKS

Transmitted herewith is a Substitute Specification for amending the enclosed patent application, the U.S. national phase of International application Serial No. PCT/EP 01/05414 which was filed in the EPO Receiving Office on May 11, 2001.

The International application was filed in the German language and enclosed with this filing is a literal translation of that International application as filed.

The enclosed Substitute Specification is submitted for the purpose of facilitating examination by correcting and clarifying the literal English translation so as to be more readily understood by a U.S. patent examiner. To further facilitate examination, the literal translation has been rearranged into a format consistent with U.S. practice. The extensive nature of the editorial revisions made herein would render it impractical and confusing to indicate changes upon the English language translation of the International application.

The enclosed Substitute Specification adds no new matter to International application PCT/EP 01/05414.

A copy of the substitute specification is enclosed with changes to the English language translation of the International patent application indicated thereon by underlining (additions to language of the translation) and brackets (deletions from language of the translation).

Claims 1 through 6 of the substitute specification are identical to those of the English language translation of the International application. Applicant has amended the substitute specification by cancelling Claims 1 through 6 without prejudice and adding new Claims 7 through 12. New Claim 7 includes all

limitations of former Claim 1, new Claim 8 includes all limitations of former Claim 2, new Claim 9 includes all limitations of former Claim 3, new Claim 10 includes all limitations of former Claim 4, new Claim 11 includes all limitations of former Claim 5 and new Claim 6 includes all limitations of former Claim 12. In each case, the new claim only restates the corresponding English language translation of the former claim in better form for U.S. examination.

Respectfully submitted,

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10/070840
JC13 Rec'd PCT/PTO 11 MAR 2002

SUBSTITUTE SPECIFICATION

Title: OPTICAL FIBER COIL FOR A FIBER-OPTIC MEASURING DEVICE AND A METHOD OF PRODUCING IT

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BACKGROUND

Field of the Invention

The present invention relates to sensor coils [an optical fiber coil] for [a] fiber optic measuring devices. More particularly, [in particular] this invention pertains to a sensor coil for a fiber optic Sagnac interferometer and [to a method for producing it] a production method therefor.

Description of the Prior Art

Optical fiber coils for fiber optic measuring devices, (i.e. [in particular] sensor coils for Sagnac interferometers such as fiber optic rate-of-rotation sensors) are responsible for generating [have the task of recording] an optical phase shift between two counterpropagating light waves [propagating therein in opposite directions in accordance with the Sagnac effect and of permitting]. This then allows measurement of rotation rate in accordance with the Sagnac effect upon measurement of the phase shift with a photoelectric [measuring] device. Measuring devices of such [this] type are known [and are denoted in general, and therefore also in brief below] as interferometers and, more specifically, [in said narrower sense] as fiber gyros.

In practice, disturbing side effects are <u>found</u>
[of]
<u>to be</u> superimposed on the measuring signal <u>in</u> such an
[s]
interferometer. <u>For example</u>, non-reciprocal variation <u>of</u> [in]
the light path inside the fiber coil, in particular, lead<u>s</u>
[of the interferometer] [to incorrect measurements by the rate-of-rotation sensor, for example]
to zero shifts and, thus, <u>measurement errors</u>. Sensitivity
to temperature transients along the optical fiber is
[after its discoverer] [are to be mentioned here, in particular. This effect]
denoted as the Shupe effect, <u>named after its discoverer</u>
(compare Shupe; Appl. Opt. <u>19</u>(5), pages 654-655 (1980)).
[the]
During a variation in ambient temperature, and as a result
thereof, a change in the temperature profile inside the
optical fiber, a zero error <u>occurs which is</u> proportional
[occurs which leads]
to the rate of temperature change. In the case of rate-
of-rotation sensors, this may lead to unacceptable
[inaccuracies, at least starting from a certain quality class]
<u>inaccuracy, for a desired sensor accuracy</u>.

[measures] [described or]
A number of <u>solutions</u> have been proposed for
[holding down] [already]
<u>reducing</u> the effect of temperature change[s]. <u>Commonly such</u>
[abovementioned] [The core of these measures was generally to fashion the]
<u>solutions attempt to arrange</u> thermal conduction in the
[optical fiber of the] [in a symmetrical way]
sensor coil optical fiber <u>symmetrically</u>. Specifically, [the theoretical
description of the] Shupe effect <u>theory</u> teaches that [the] reciprocity error occurs
only when segments that are at an equal distance from the
[total length of the]
center of the optical fiber are subjected to unequal
temperature influences. This finding has led to
[measures aimed at designing the] [wound up to form]
structural arrangement of the optical fiber <u>forming</u> a
[with the greatest]
[sensor] coil <u>for maximum</u> possible thermal symmetry. <u>This</u>

is chiefly accomplished by known quadrupole winding [It is what is termed the quadrupole winding technique] (compare Bergh: G.L. Report No. 3586, Stanford University 1983, US 4,781,461, US 4,856,900 JP-Patent Abstracts of Japan: 63-33612 A, P-727, July 8, 1988, Vol. 12, No. 240 and 1-305310 A, P-1012, February 23, 1990, Vol. 14, No. 101) or [what is termed the] octupole winding [technique] (compare EP 0 614 518) [that has chiefly become known]. In such [these] winding techniques, the turns of [the] optical fiber are laid precisely next to one another in each [winding] layer. Crossovers and gaps between individual fiber turns are [to be] avoided by a very precise and relatively [comparatively] -expensive winding technique. Other approaches [to the solution as are] described, for example, in EP 0 69 760 and US 5,543,482 require each winding layer to be embedded in an elastic buffer material.

With such [In these] known methods for reducing nonreciprocal light path variations [in the light path] due to [caused by] the Shupe effect, fundamental system-induced problems remain [continue to arise, however]. Starting from the second winding layer, the turn-to-turn [from turn-to-turn] gradient of the optical fiber does not occur in a uniform spiral. [The] Fibers are laid in [the] grooves formed by the layer below [situated therebelow]. Since the gradient changes [its] direction from layer to layer, [a] crossover must occur [take place] with each revolution. The locus of [these] crossovers is stepwise [in a step fashion] limited to a constricted space. As [follows from the diagrammatic illustration of] illustrated in Figure 3, [in the attached drawings] the crossover region of all [the] turns of a layer occurs [is situated] in a small angle segment

δ, particularly when a [for a desired] narrow layer winding is desired. The high demands placed upon [on] the precision of [the] coil winding result in [entail] complicated winding methods and require correspondingly expensive winding equipment. It must [chiefly] be taken into account in such [this] case that, due to [because of] its material properties, the glass fiber employed [used] as optical conductor possesses [has] an inherent elastic tension that [which] tends to bring [the fiber into] it to a preferred [position], generally stretched, position. Bending or torsional stresses within a [inside the] fiber can lead to [the fiber] it lying on a winding body in an undulating configuration [manner]. Such [This] waviness can lead, in turn, to crossovers or gaps between the turns within a layer. For [an] automatic winding, these risks demand a large [constitute a high] outlay on machinery and a high level of expertise [expert knowledge] and skill from the production staff to avoid such faults [if such faults are to be avoided].

[In order to reduce nonreciprocity errors due to the Shupe effect] DE 36 32 730 discloses the avoidance of [has already disclosed the proposal of avoiding] bending losses at crossovers, to reduce nonreciprocity errors due to the Shupe effect by providing a winding with a single [only one] layer which distributes or mixes turns randomly that [and] are then fixed in a specific volume with the aid of an adhesive, the winding core being subsequently removed. Apart from the fact that this type of winding technique unavoidably leads to [coils of] large volume coil structures, investigations have shown that the avoidance of bending

losses, although reducing [leading to an improvement in] nonreciprocal phase errors, cannot eliminate [the] Shupe effect problem.

If, in accordance with a proposal by Dyott, the opposite approach [way] is adopted and [the] turns are randomized in not only the axial but also the radial direction, the winding pattern no longer exhibits any layer winding and, [in order] to achieve a coil of low volume, it is necessary for the fiber winding disk to be held together with the aid of a fixing means, at least whenever [in accordance with the proposal by Dyott,] a coil former is to be dispensed with (compare R.B. Dyott: Reduction of the Shupe effect in fiberoptic gyros; The Random-Wound Coil, Electronics Letters, November 7, 1996, Vol 32, No. 23, pages 2177 and 2178).

Although it can be produced relatively easily in [terms of method, by] comparison with the quadrupole winding technique, as it is currently applied in the various method variants mentioned above [, this] winding applied by random distribution cannot lead to a sufficient improvement in [the] zero drift in [the case of] fiber gyros for operation [which are to be operated] with high accuracy over a specific [on the basis of a prescribed specification in the] temperature range [of, for example] (e.g. −55°C to +80°C).

SUMMARY AND OBJECTS OF THE INVENTION

It is therefore an [the] object of the present invention to provide an optical fiber coil[s] for a fiber optic Sagnac interferometer[s] [and a method for producing them] that is characterized [which are distinguished] by outstanding freedom from zero drift within prescribed temperature limits and rates of temperature change.

It is another object of the invention to provide a method for producing an optical fiber coil in accordance with the preceding object.

The invention addresses the above objects by providing, in a first aspect, an improvement in [According to the invention the invention is characterized, in the case of] a method for producing an optical fiber coil for a fiber optic measuring device of the type in which the fiber coil is formed by winding an optical fiber. The improvement provided by this invention comprises applying [in that in order to reduce nonreciprocal variations in the light path in the fiber coil during winding] the optical fiber [is applied] to a winding body in a quadrupole winding pattern in [directly] successive winding layers so [such] that the turns of [in the] individual winding layers have, at irregular spacings, as large a number of crossover points as possible. As a result, nonreciprocal variation is reduced in the light path formed by the fiber.

In a second aspect, the invention provides an

optical fiber coil for a fiber optic Sagnac interferometer [is, furthermore, characterized in accordance with the invention by]. Such coil includes a winding body [to which] and an optical fiber that is applied to the winding body in directly successive winding layers in a quadrupole winding pattern with a plurality of irregularly-spaced crossover points in [the] individual winding layers.

The preceding and other features of the invention will become further apparent from the detailed description that follows. Such description is accompanied by a set of drawing figures. Numerals of the drawing figures, corresponding to those of the written description, point to the features of the invention with like numerals referring to like features throughout both the drawing figures and the written text.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side elevation view of [shows] a winding body with [turns of] an optical conductor wound thereon;

Figure 2 is a sectional view taken [shows a section] through the center plane of a coil with a winding body; and

Figure 3 is a side elevation view of a winding body with an [shows a known] optical fiber coil [in the case of] wound thereon in

accordance with the prior art in which the crossovers of oppositely wound layers are situated in a narrow winding range when a narrow layer winding is applied.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 illustrates a winding body 1 with flanges 2 and 3 at [the] its ends. Turns of an optical fiber 4 are applied to the winding body 1, the [illustrated] turns of the illustrated lowest layer [being at] having a large spacing from one another. [As may be seen from] Referring now to Figure 2, the turns of a second layer of the optical fiber 4 [come to] lie in [the] interspaces 5 of the first layer. The turns of the lower layer are displaced at various points marked by the reference numeral 6 so [in such a way] that the interspaces are enlarged. Consequently, the interspace is reduced in turn in relation to respectively neighboring turns 7. Starting from the third layer, a top surface of the overall winding is produced which can be characterized as an irregular winding shape.

It is important for the invention that the combined application of a quadrupole winding pattern using a coil body, and the arrangement [application] of the turns of [in] winding layers at irregular spacings with as many crossover points as possible (i.e. [, specifically] without the use of fixing or buffer

means) leads [in this totality] to a very substantial reduction in the nonreciprocal phase shifts and/or zero shifts, caused by the Shupe effect, in [of] an interferometer equipped with such [a] fiber coil.

Detailed investigations into the [influencing] factors of tensile stress, arrangement of interlayers of a buffer or fixing means between the winding layers, and number of [the] fiber crossovers [occurring] on sensitivity to temperature transients and [the] polarization [the] cross-coupling (particularly [, in particular] in the case of polarization-maintaining optical fibers) has led to the optimal solution of [implemented by] the invention.

Most significantly, [Above all] the method of [according to] the invention is characterized in that, by contrast to [with the] prior assumptions and preconditions of the quadrupole winding technique, [- given a large number of crossovers of the optical fiber -] there is a distinct improvement in the sensitivity to temperature transients in the direction of substantially smaller nonreciprocal phase shifts when there are a large number of crossovers of the optical fiber.

According to the invention, the winding is configured [in this case] such that the region in which the crossovers take place is not restricted to a small angular range [of the coil], but

that, rather, the locations of the crossovers are distributed over the entire extent of the coil. [Furthermore] It has been established as a characteristic of the invention that the factors of tensile stress and buffer layer, which have previously been regarded as significant influencing variables, are of little significance to [for] the favorable result obtained. If, in particular, the tensile stress applied during winding is kept in the [a] range of [from] approximately 10 cN to approximately 20 cN, [the] polarization cross-coupling between the intrinsic polarization modes of the optical fiber is not significantly affected [does not change significantly] by the addition or omission of elastic buffer layers between the individual fiber layers. The crossover factor [of crossovers] is of comparably little significance [therefor].

It is important [for the teaching according to the invention] that fixing and/or buffer means are not required, since they do not [improve the desired result. However, they do not] impair it, either. It has merely been observed that, when no adhesives are used, the polarization cross-coupling can be degraded in the combination with high tensile stress (i.e. [, that is to say] outside the previously-mentioned range of approximately 10 to 20 cN).

In a [With regard to the] method for producing optical fiber coils having [with] the desired properties, this [the object set] is achieved by the [according to the invention with the aid of]

following winding technique that [methods which] can be accomplished [realized] simply in [terms of] production: [engineering] a winding body is provided having flanges, one at each end [which has a flange at both axial ends]. The method is based upon [basis is provided by] the known quadrupole winding pattern, referred to, [known] inter alia, in [from] the literature referenced [quoted] above. In this case, the entire length of the fiber, which is to be wound onto a sensor coil, is first wound onto a dispenser coil. Half of the fiber length is then [now] wound off from one dispenser coil onto a second dispenser coil. The sensor coil is then wound, starting from the midpoint [middle] of the total fiber length. The first step in this process is to wind a layer from the first dispenser coil, and then a double layer from the second dispenser coil. Double layers are now alternately wound from the first and [or] second dispenser coils onto the sensor coil to be produced until the entire length [quantity] of fiber held [located] on the dispenser coils is utilized [used up]. In order to produce many irregular fiber crossovers, the gradient of the winding is set such that a gap of approximately 50% of the fiber diameter exists [arises] in each case between (two) turns. The [A certain] waviness of the fiber [leads] creates [to] a variable spacing between neighboring turns, but [in such a way that] on average, the spacings over a winding layer correspond to approximately half the diameter of the optical fiber. Unlike the prior art, the fiber is not forced into a prescribed position by positive guidance [as previously employed]. The turns of a

layer situated therebelow fall into the gap thus formed. The positions of the turns of the layer located below [therebelow] can be displaced in this case such that the gap spacings become variable or irregular. The pattern produced in this way becomes random with irregular crossovers starting from the third layer. [Irregular crossovers occur.]

In accordance with the method of the invention, there is no need for fixing or buffer means to separate the winding layers. The relatively-close mutual penetration of the winding layers [thereby achieved] leads to a more uniform thermal distribution of fiber sections equally spaced from the midpoint of the coil.

The method of [according to] the invention does not require [on a conventional automatic winding machine] adding devices [any device] for applying or curing a fixing means to a conventional automatic winding machine. It is also [likewise] possible to eliminate a need for precise [exact] control of the individual fiber positions. The previously-unavoidable complexity of [the] winding machines required for producing such fiber coils can be drastically reduced.

While this invention has been described with reference to its presently-preferred embodiment, it is not limited thereto. Rather, the invention is only limited

insofar as it is defined by the following set of patent claims and includes within its scope all equivalents thereof.

What is claimed is: [Patent claims]

1. A method for producing an optical fiber coil for a fiber-optic measuring device, characterized in that, in order to reduce nonreciprocal variations in the light path, in the fiber coil during winding of the same, the optical fiber is applied to a winding body in a quadrupole winding pattern in directly successive winding layers such that the turns in the individual winding layers have, at irregular spacings, as large a number of crossover points as possible.

2. The method as claimed in claim 1, characterized in that the optical fiber is wound in each winding layer such that the generally irregular spacings between individual turns correspond on average approximately to half the diameter of the optical fiber.

3. An optical fiber coil of a fiber-optic Sagnac interferometer, characterized by a winding body (1) to which the optical fiber (4) is applied in directly successive winding layers in a quadrupole winding pattern with a plurality of irregularly spaced crossover points in the individual winding layers.

4. The optical fiber coil as claimed in claim 3, characterized in that variable spacings between the turns are present in each winding layer, these spacings corresponding on average, however, to half the diameter of the optical fiber.

5. The optical fiber coil as claimed in claim 3 or 4, characterized in that the first layer of turns of the optical fiber (4) is applied to the winding body (1) directly and without fixing or buffer means.

6. The optical fiber coil as claimed in claim 3 or 4, characterized in that a fixing or buffer means is present between the winding layers.

ABSTRACT

An optical fiber coil for a fiber-optic

[In order to reduce the sensitivity of a fiber optic sensor coil to transients along the*

measuring device and a method for producing it. An optical fiber is applied

[the invention proposes the application of the optical fiber]

to a winding body [,] in a quadrupole winding pattern in directly successive winding layers such that the turns of [in] the individual winding layers have, at irregular spacings, as large a number of crossover points as possible. The spacings between the individual turns in each winding layer are variable, but, on average, they correspond to approximately half the diameter of the optical fiber. The optical fiber coil is preferably applied to the winding body without the use of fixing and buffer means.

*optical fiber (4) of the coil, and thereby to reduce reciprocity errors produced in the case of fiber optic Sagnac interferometers,]

10/070840
JC13 Rec'd PCT/PTO 11 MAR 2002

SUBSTITUTE SPECIFICATION

Title: OPTICAL FIBER COIL FOR A FIBER-OPTIC MEASURING DEVICE AND A METHOD OF PRODUCING IT

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BACKGROUND

Field of the Invention

The present invention relates to sensor coils for fiber optic measuring devices. More particularly, this invention pertains to a sensor coil for a fiber optic Sagnac interferometer and a production method therefor.

Description of the Prior Art

Optical fiber coils for fiber optic measuring devices, (i.e. sensor coils for Sagnac interferometers such as fiber optic rate-of-rotation sensors) are responsible for generating an optical phase shift between two counterpropagating light waves. This then allows measurement of rotation rate in accordance with the Sagnac effect upon measurement of the phase shift with a photoelectric device. Measuring devices of such type are known as interferometers and, more specifically, as fiber gyros.

In practice, disturbing side effects are found to be superimposed on the measuring signal in such an interferometer. For example, non-reciprocal variation of the light path inside the fiber coil, in particular, leads to zero shifts and, thus, measurement errors. Sensitivity to temperature transients along the optical fiber is denoted as the Shupe effect, named after its discoverer (compare Shupe; Appl. Opt. 19(5), pages 654-655 (1980)). During a variation in ambient temperature, and as a result thereof, a change in the temperature profile inside the optical fiber, a zero error occurs which is proportional to the rate of temperature change. In the case of rate-of-rotation sensors, this may lead to unacceptable inaccuracy, for a desired sensor accuracy.

A number of solutions have been proposed for reducing the effect of temperature change. Commonly such solutions attempt to arrange thermal conduction in the sensor coil optical fiber symmetrically. Specifically, Shupe effect theory teaches that reciprocity error occurs only when segments that are at an equal distances from the center of the optical fiber are subjected to unequal temperature influences. This finding has led to structural arrangement of the optical fiber forming a sensor coil for maximum possible thermal symmetry. This

is chiefly accomplished by known quadrupole winding (compare Bergh: G.L. Report No. 3586, Stanford University 1983, US 4,781,461, US 4,856,900 JP-Patent Abstracts of Japan: 63-33612 A, P-727, July 8, 1988, Vol. 12, No. 240 and 1-305310 A, P-1012, February 23, 1990, Vol. 14, No. 101) or octupole winding (compare EP 0 614 518). In such winding techniques, the turns of optical fiber are laid precisely next to one another in each layer. Crossovers and gaps between individual fiber turns are avoided by a very precise and relatively-expensive winding technique. Other approaches described, for example, in EP 0 69 760 and US 5,543,482 require each winding layer to be embedded in an elastic buffer material.

With such known methods for reducing nonreciprocal light path variations due to the Shupe effect, fundamental system-induced problems remain. Starting from the second winding layer, the turn-to-turn gradient of the optical fiber does not occur in a uniform spiral. Fibers are laid in grooves formed by the layer below. Since the gradient changes direction from layer to layer, crossover must occur with each revolution. The locus of crossovers is stepwise limited to a constricted space. As illustrated in Figure 3, the crossover region of all turns of a layer occurs in a small angle segment

δ, particularly when a narrow layer winding is desired. The high demands placed upon the precision of coil winding result in complicated winding methods and require correspondingly expensive winding equipment. It must be taken into account in such case that, due to its material properties, the glass fiber employed as optical conductor possesses an inherent elastic tension that tends to bring it to a preferred, generally stretched, position. Bending or torsional stresses within a fiber can lead to it lying on a winding body in an undulating configuration. Such waviness can lead, in turn, to crossovers or gaps between the turns within a layer. For automatic winding, these risks demand a large outlay on machinery and a high level of expertise and skill from the production staff to avoid such faults.

DE 36 32 730 discloses the avoidance of bending losses at crossovers, to reduce nonreciprocity errors due to the Shupe effect by providing a winding with a single layer which distributes or mixes turns randomly that are then fixed in a specific volume with the aid of an adhesive, the winding core being subsequently removed. Apart from the fact that this type of winding technique unavoidably leads to large volume coil structures, investigations have shown that the avoidance of bending

losses, although reducing nonreciprocal phase errors, cannot eliminate Shupe effect problem.

If, in accordance with a proposal by Dyott, the opposite approach is adopted and turns are randomized in not only the axial but also the radial direction, the winding pattern no longer exhibits any layer winding and, to achieve a coil of low volume, it is necessary for the fiber winding disk to be held together with the aid of a fixing means, at least whenever a coil former is to be dispensed with (compare R.B. Dyott: Reduction of the Shupe effect in fiberoptic gyros; The Random-Wound Coil, Electronics Letters, November 7, 1996, Vol 32, No. 23, pages 2177 and 2178).

Although it can be produced relatively easily in comparison with the quadrupole winding technique, as it is currently applied in the various method variants mentioned above winding applied by random distribution cannot lead to a sufficient improvement in zero drift in fiber gyros for operation with high accuracy over a specific temperature range(e.g. -55° C to +80° C).

SUMMARY AND OBJECTS OF THE INVENTION

It is therefore an object of the present invention to provide an optical fiber coil for a fiber optic Sagnac interferometer that is characterized by outstanding freedom from zero drift within prescribed temperature limits and rates of temperature change.

It is another object of the invention to provide a method for producing an optical fiber coil in accordance with the preceding object.

The invention addresses the above objects by providing, in a first aspect, an improvement in a method for producing an optical fiber coil for a fiber optic measuring device of the type in which the fiber coil is formed by winding an optical fiber. The improvement provided by this invention comprises applying the optical fiber to a winding body in a quadrupole winding pattern in successive winding layers so that the turns of individual winding layers have, at irregular spacings, as large a number of crossover points as possible. As a result, nonreciprocal variation is reduced in the light path formed by the fiber.

In a second aspect, the invention provides an

optical fiber coil for a fiber optic Sagnac interferometer. Such coil includes a winding body and an optical fiber that is applied to the winding body in directly successive winding layers in a quadrupole winding pattern with a plurality of irregularly-spaced crossover points in individual winding layers.

The preceding and other features of the invention will become further apparent from the detailed description that follows. Such description is accompanied by a set of drawing figures. Numerals of the drawing figures, corresponding to those of the written description, point to the features of the invention with like numerals referring to like features throughout both the drawing figures and the written text.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side elevation view of a winding body with an optical conductor wound thereon;

Figure 2 is a sectional view taken through the center plane of a coil with a winding body; and

Figure 3 is a side elevation view of a winding body with an optical fiber coil wound thereon in

accordance with the prior art in which the crossovers of oppositely wound layers are situated in a narrow winding range when a narrow layer winding is applied.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 illustrates a winding body 1 with flanges 2 and 3 at its ends. Turns of an optical fiber 4 are applied to the winding body 1, the turns of the illustrated lowest layer having a large spacing from one another. Referring now to Figure 2, the turns of a second layer of the optical fiber 4 lie in interspaces 5 of the first layer. The turns of the lower layer are displaced at various points marked by the reference numeral 6 so that the interspaces are enlarged. Consequently, the interspace is reduced in turn in relation to respectively neighboring turns 7. Starting from the third layer, a top surface of the overall winding is produced which can be characterized as an irregular winding shape.

It is important for the invention that the combined application of a quadrupole winding pattern using a coil body, and the arrangement of the turns of winding layers at irregular spacings with as many crossover points as possible (i.e. without the use of fixing or buffer

means) leads to a very substantial reduction in the nonreciprocal phase shifts and/or zero shifts, caused by the Shupe effect, in an interferometer equipped with such fiber coil.

Detailed investigations into the factors of tensile stress, arrangement of interlayers of a buffer or fixing means between the winding layers, and number of fiber crossovers on sensitivity to temperature transients and polarization cross-coupling (particularly in the case of polarization-maintaining optical fibers) has led to the optimal solution of the invention.

Most significantly, the method of the invention is characterized in that, by contrast to prior assumptions and preconditions of the quadrupole winding technique, there is a distinct improvement in the sensitivity to temperature transients in the direction of substantially smaller nonreciprocal phase shifts when there are a large number of crossovers of the optical fiber.

According to the invention, the winding is configured such that the region in which the crossovers take place is not restricted to a small angular range, but

that, rather, the locations of the crossovers are distributed over the entire extent of the coil. It has been established as a characteristic of the invention that the factors of tensile stress and buffer layer, which have previously been regarded as significant influencing variables, are of little significance to the favorable result obtained. If, in particular, the tensile stress applied during winding is kept in the range of approximately 10 cN to approximately 20 cN, polarization cross-coupling between the intrinsic polarization modes of the optical fiber is not significantly affected by the addition or omission of elastic buffer layers between the individual fiber layers. The crossover factor is of comparably little significance.

It is important that fixing and/or buffer means are not required, since they do not impair it, either. It has merely been observed that, when no adhesives are used, the polarization cross-coupling can be degraded in the combination with high tensile stress (i.e. outside the previously-mentioned range of approximately 10 to 20 cN).

In a method for producing optical fiber coils having the desired properties, this is achieved by the

following winding technique that can be accomplished simply in production: a winding body is provided having flanges, one at each end. The method is based upon the known quadrupole winding pattern, referred to, inter alia, in the literature referenced above. In this case, the entire length of the fiber, which is to be wound onto a sensor coil, is first wound onto a dispenser coil. Half of the fiber length is then wound off from one dispenser coil onto a second dispenser coil. The sensor coil is then wound, starting from the midpoint of the total fiber length. The first step in this process is to wind a layer from the first dispenser coil, and then a double layer from the second dispenser coil. Double layers are now alternately wound from the first and second dispenser coils onto the sensor coil to be produced until the entire length of fiber held on the dispenser coils is utilized. In order to produce many irregular fiber crossovers, the gradient of the winding is set such that a gap of approximately 50% of the fiber diameter exists in each case between (two) turns. The waviness of the fiber creates a variable spacing between neighboring turns, but, on average, the spacings over a winding layer correspond to approximately half the diameter of the optical fiber. Unlike the prior art, the fiber is not forced into a prescribed position by positive guidance. The turns of a

layer situated therebelow fall into the gap thus formed. The positions of the turns of the layer located below can be displaced in this case such that the gap spacings become variable or irregular. The pattern produced in this way becomes random with irregular crossovers starting from the third layer.

In accordance with the method of the invention, there is no need for fixing or buffer means to separate the winding layers. The relatively-close mutual penetration of the winding layers leads to a more uniform thermal distribution of fiber sections equally spaced from the midpoint of the coil.

The method of the invention does not require adding devices for applying or curing a fixing means to a conventional automatic winding machine. It is also possible to eliminate a need for precise control of the individual fiber positions. The previously-unavoidable complexity of winding machines required for producing such fiber coils can be drastically reduced.

While this invention has been described with reference to its presently-preferred embodiment, it is not limited thereto. Rather, the invention is only limited

insofar as it is defined by the following set of patent claims and includes within its scope all equivalents thereof.

What is claimed is:

1. A method for producing an optical fiber coil for a fiber-optic measuring device, characterized in that, in order to reduce nonreciprocal variations in the light path, in the fiber coil during winding of the same, the optical fiber is applied to a winding body in a quadrupole winding pattern in directly successive winding layers such that the turns in the individual winding layers have, at irregular spacings, as large a number of crossover points as possible.

2. The method as claimed in claim 1, characterized in that the optical fiber is wound in each winding layer such that the generally irregular spacings between individual turns correspond on average approximately to half the diameter of the optical fiber.

3. An optical fiber coil of a fiber-optic Sagnac interferometer, characterized by a winding body (1) to which the optical fiber (4) is applied in directly successive winding layers in a quadrupole winding pattern with a plurality of irregularly spaced crossover points in the individual winding layers.

4. The optical fiber coil as claimed in claim 3, characterized in that variable spacings between the turns are present in each winding layer, these spacings corresponding on average, however, to half the diameter of the optical fiber.

5. The optical fiber coil as claimed in claim 3 or 4, characterized in that the first layer of turns of the optical fiber (4) is applied to the winding body (1) directly and without fixing or buffer means.

6. The optical fiber coil as claimed in claim 3 or 4, characterized in that a fixing or buffer means is present between the winding layers.

ABSTRACT

An optical fiber coil for a fiber-optic measuring device and a method for producing it. An optical fiber is applied to a winding body in a quadrupole winding pattern in directly successive winding layers such that the turns of the individual winding layers have, at irregular spacings, as large a number of crossover points as possible. The spacings between the individual turns in each winding layer are variable, but, on average, they correspond to approximately half the diameter of the optical fiber. The optical fiber coil is preferably applied to the winding body without the use of fixing and buffer means.